Characterizing the X ray gun (Au target) with NaI(Tl) detector and GEM detector

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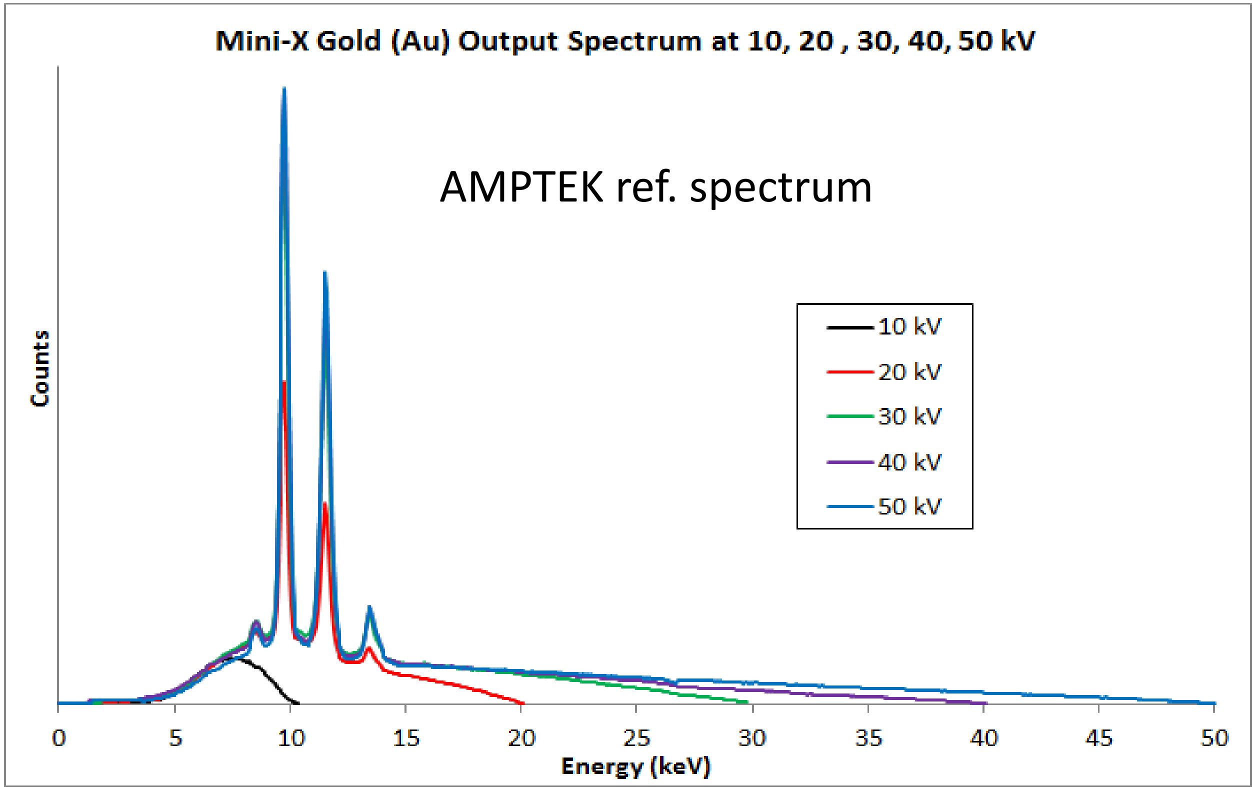
2015-06-22

EIC tracking R&D weekly meeting

Motivation

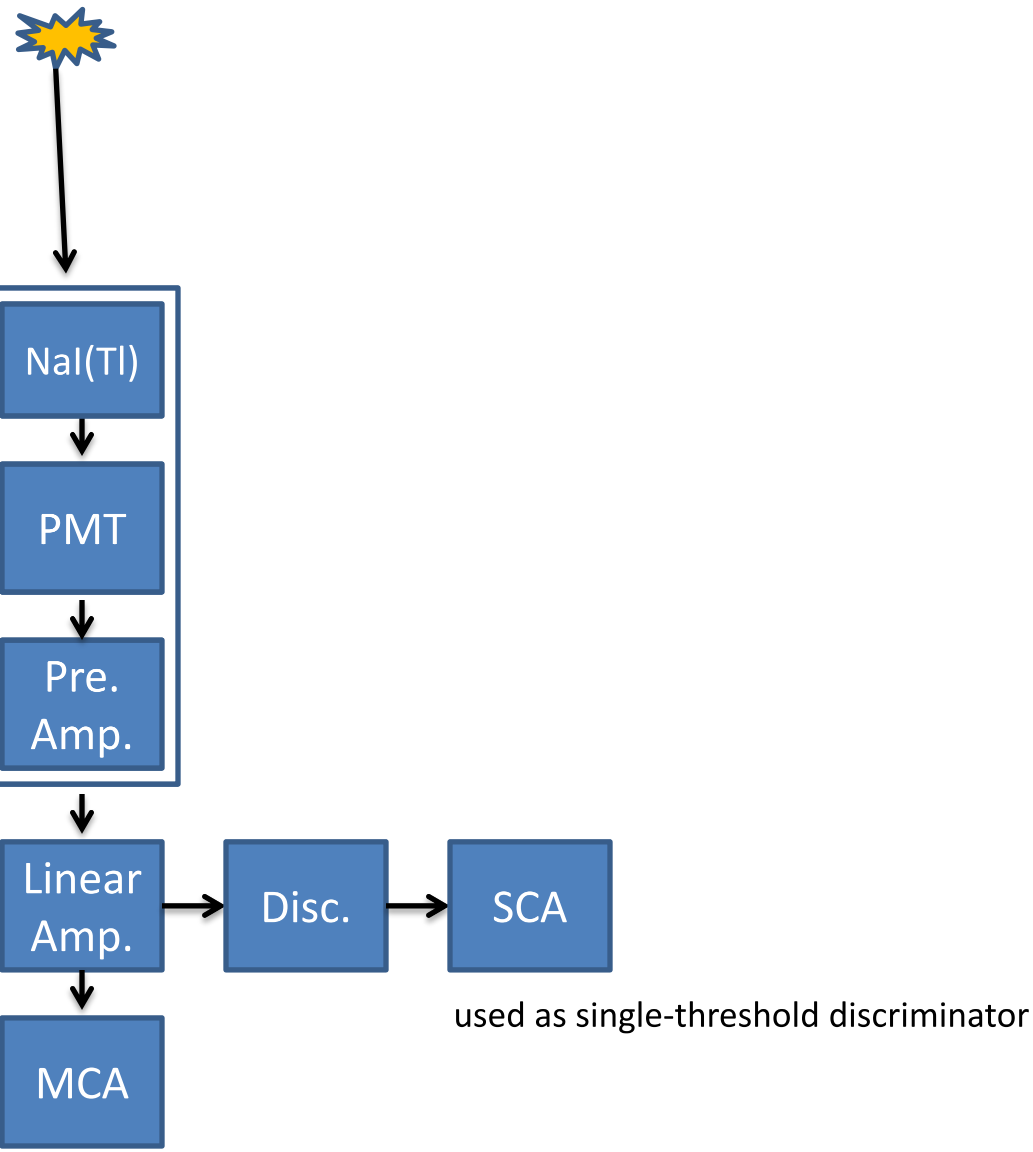
- To understand our X-ray gun better
- To prepare for high rate tests on large GEM detectors.

The official spectrum of X ray gun (Au target) (what we expect)



Setup for the NaI(Tl) detector

radiation



Canberra
PMT:2007P
(operated at 1.1kV)
NaI(Tl): 802
2×2 inches

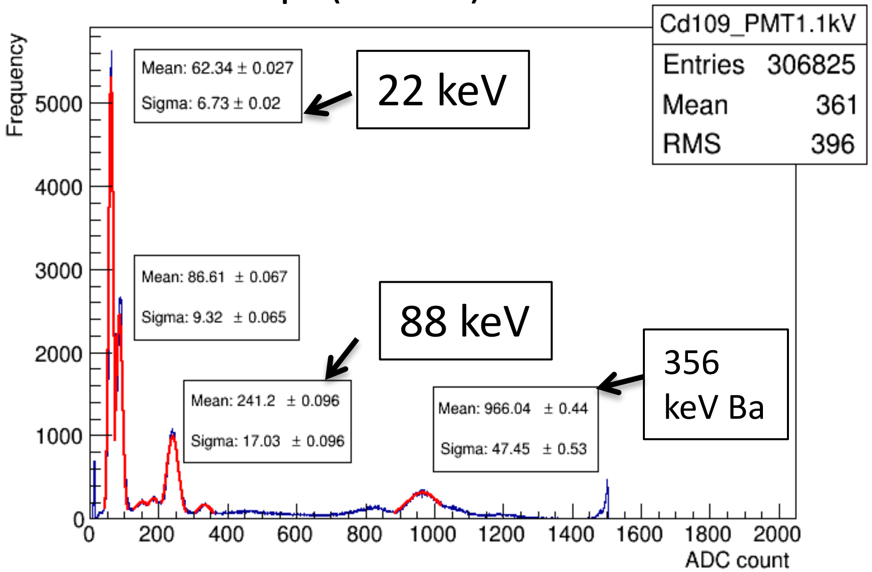
The device has a
0.5 mm Aluminum
window

Fe-55 5.9 keV X rays
can not penetrate
the Al window,
no signal was
observed.

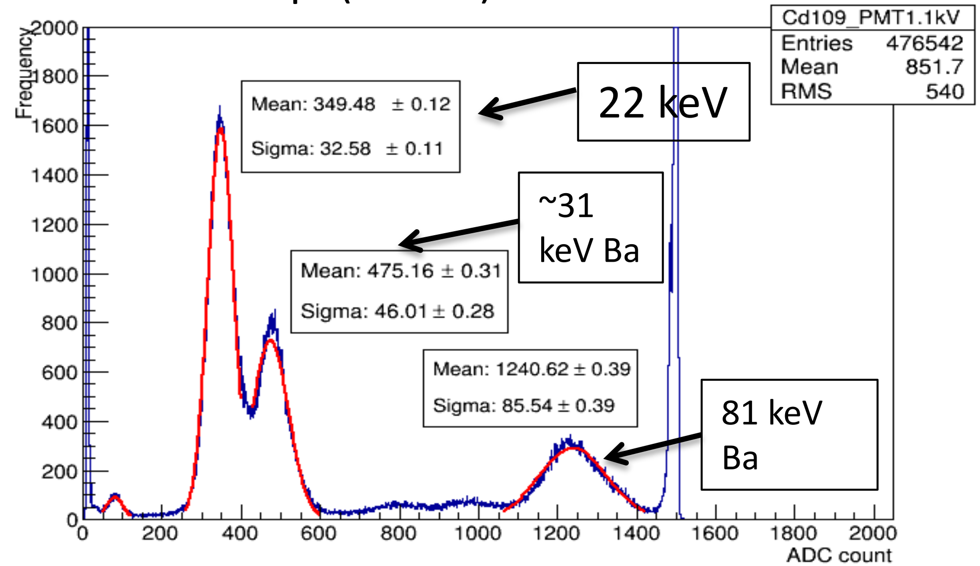
Cs-137 and Cd-109 calibration of NaI(Tl)

- PMT voltage 1.1 kV;

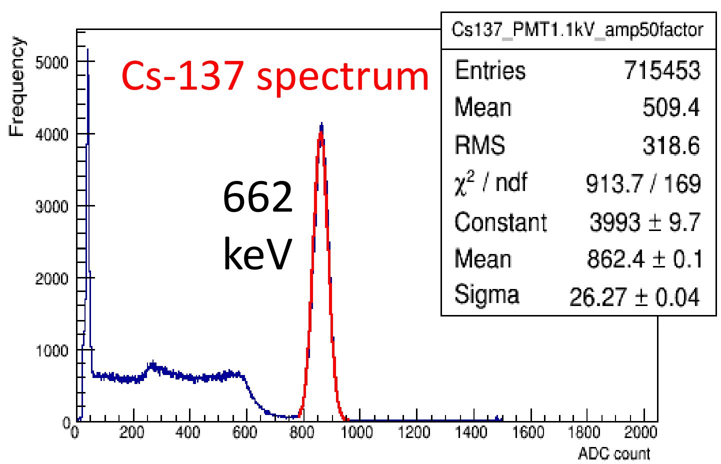
Linear amp. (coarse) factor 100



Linear amp. (coarse) factor 500



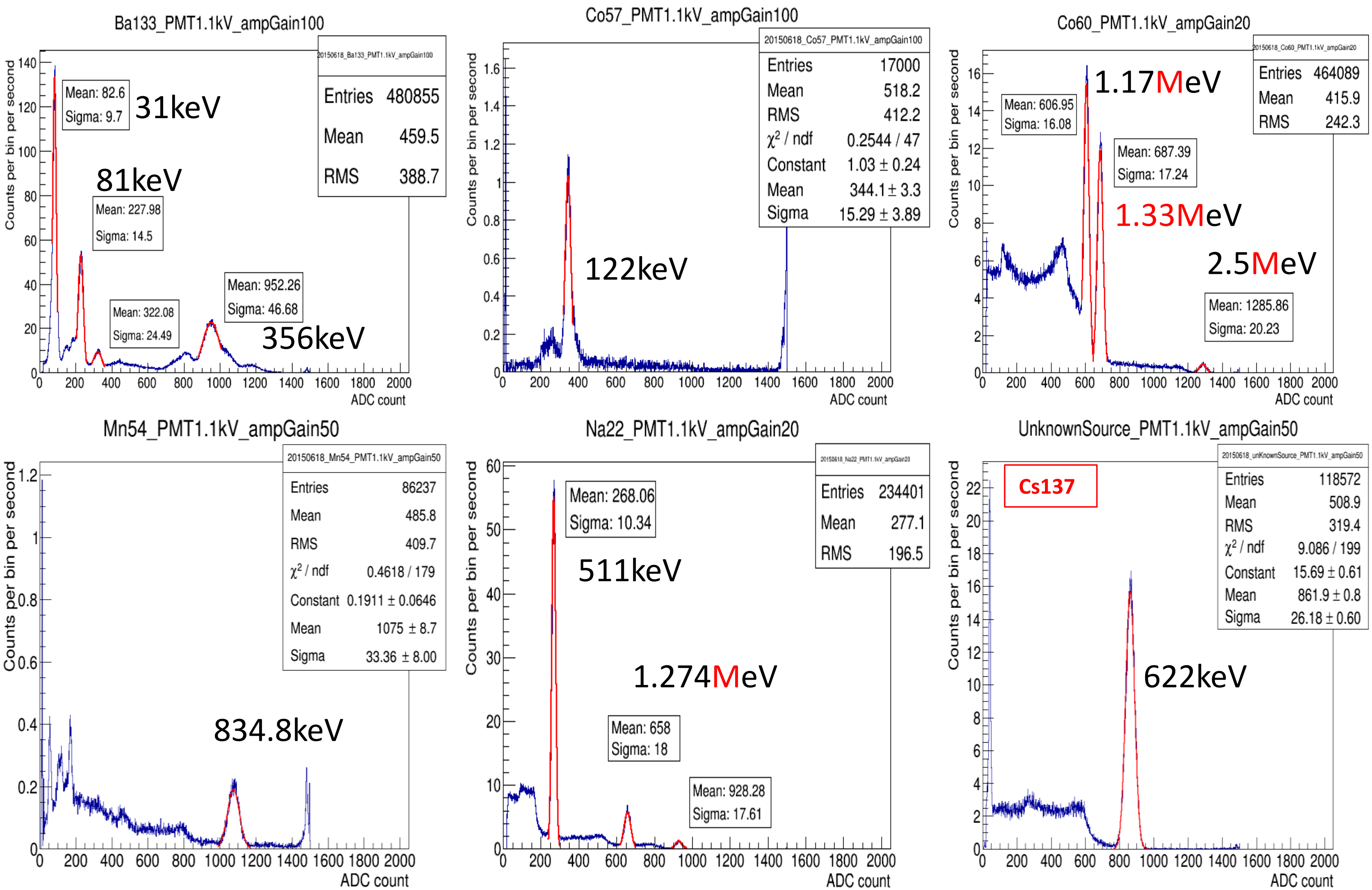
Linear amp. (coarse) factor 50



- Linear amp. factor has to be adjusted to allow the peaks to be well measured over full energy range
- Non-linearity of the MCA is ignored, the reason to do so is that we don't have small energy X-ray sources to calibrate the system.
- It turned out that our Cd-109 is not pure, it appears that it may contain some contamination with Ba-133.

- For X ray gun tests, linear amp. factor is set to 500.

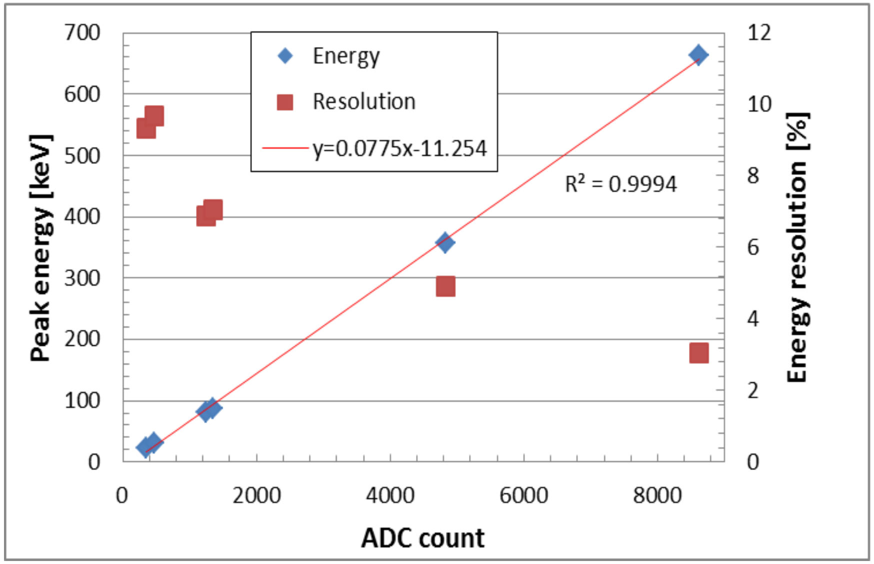
spectra for other sources obtained with the NaI(Tl) detector



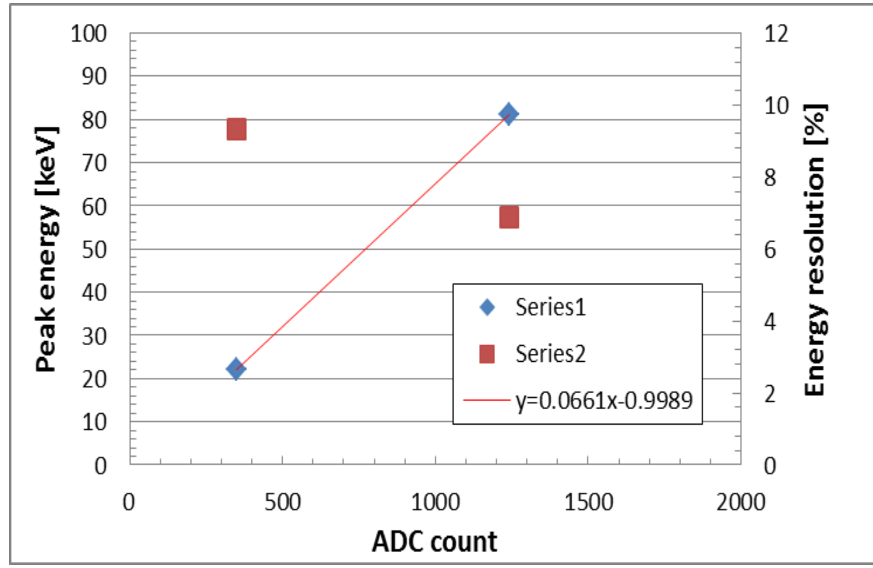
- These spectra indicate non-linearity of our electronics (linear amp.).

Calibration of the electronic system (at amp. gain 500):

- Use all peaks of both radiation sources



- Use peaks of < 100 keV (2 points)



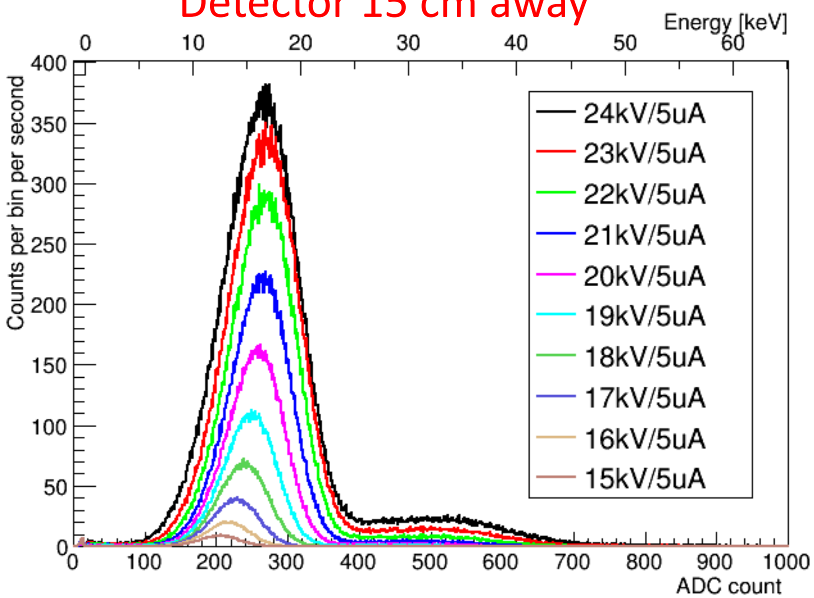
- The 2-point calibration (on the right) is taken; reasons:

(1) To use only the Cd-109 spectrum taken with linear amp. gain of 500. Cd-109 has a 22 keV line which is close to the energies that X ray gun outputs;
(2) On that spectrum, the 22 keV and 81 keV peaks are more or less single energy peaks, the 31 keV peak actually contains different energies (30.3,30.6,30.9 keV) that are not resolved. So, 31 keV peak is not used.

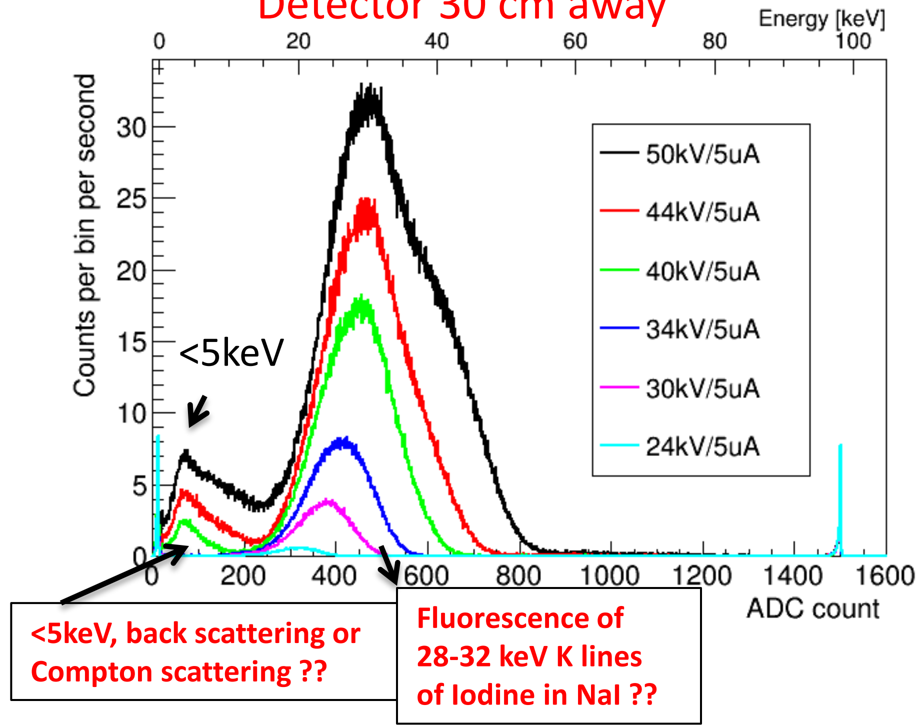
X-ray gun voltage scan at 5 µA, 1 mm collimator is used

- For each tested voltage, there is only one peak on the spectrum;
- Energy scale is calibrated with the previous Cd-109 spectrum (at amp. gain 500).

Detector 15 cm away



Detector 30 cm away



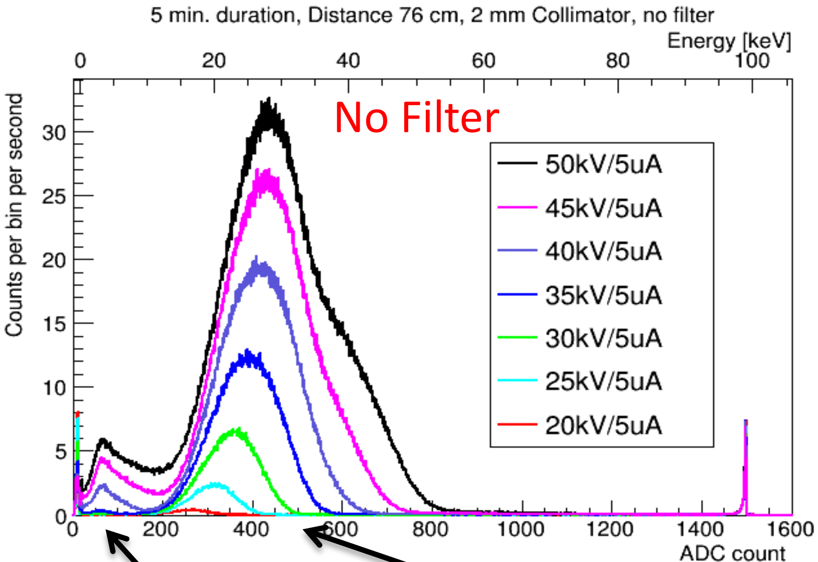
To **reduce pileup** and to speed up tests:

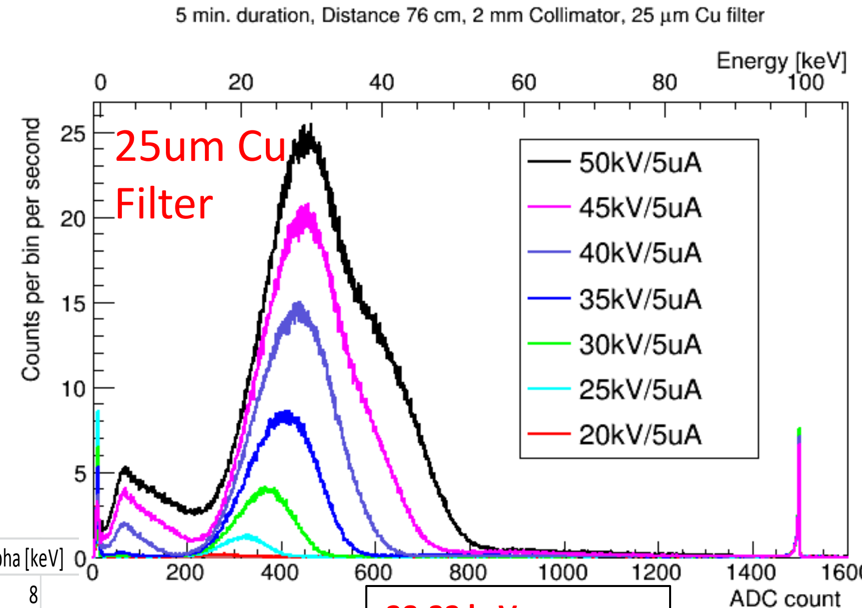
(1) X ray gun is put 30 cm (15 cm) away from detector when testing 24kV-50kV (12kV-24kV). For each case, at highest tested voltage there is a little pileup which distorts the spectrum by adding a shoulder to the right and shifting the main peak to the left.

(2) The distance to the detector is very close (~ 1cm) when testing 11kV. Rate is very low even for this situation. Could not take 10kV data (don't make into the NaI)

(3) While changing the distance, X rays may be hitting different positions on the detector, this could give small bias.

WITH FILTERS: X ray gun is 76cm away from NaI, 2mm collimator; Amp. Gain 500.



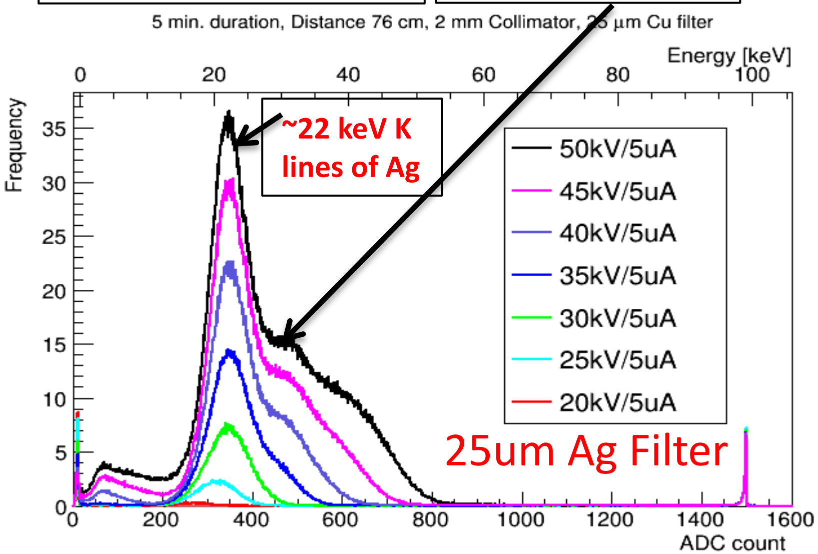


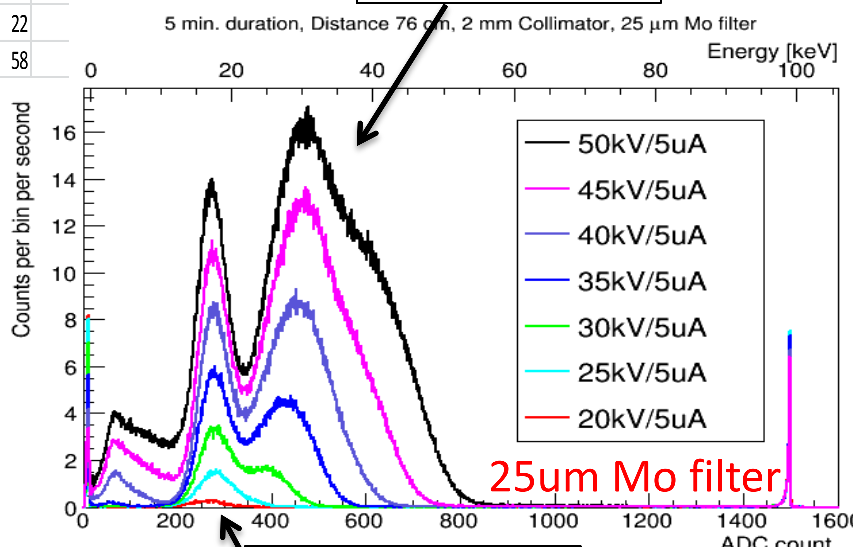
<5keV, back scattering or Compton scattering ??

28-32 keV K lines of Iodine ??

Material	K alpha [keV]
Cu	8
Al	1.5
Mo	17
Ag	22
W	58

28-32 keV K lines of Iodine ??



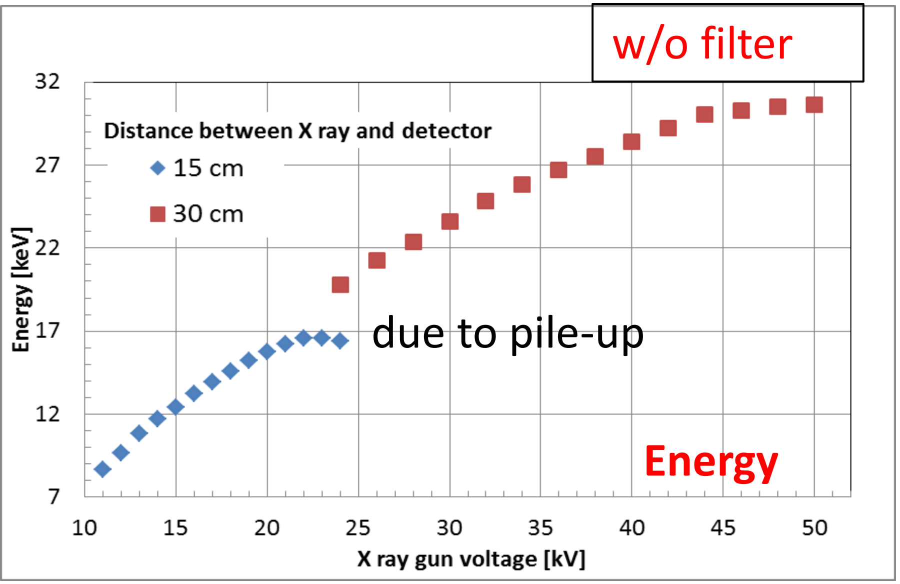


~17 keV K lines of Mo

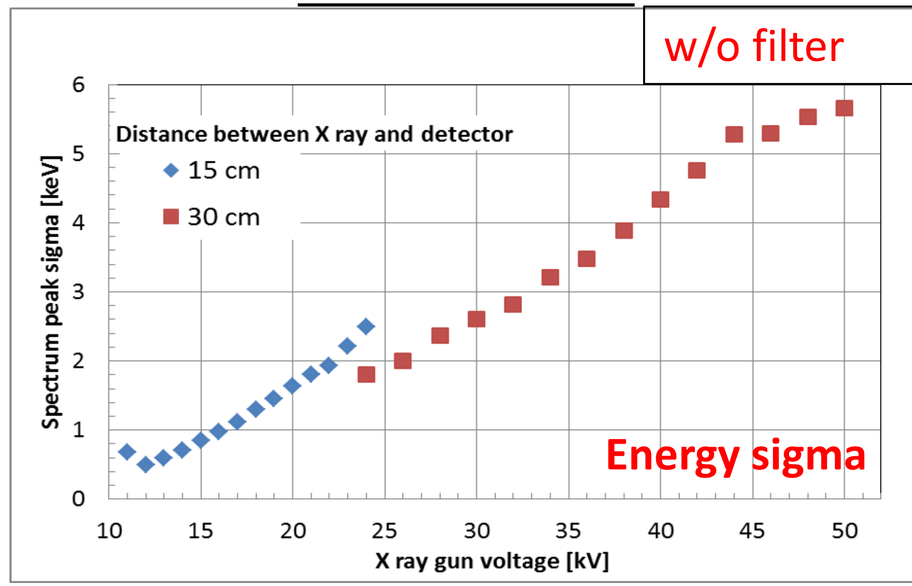
- **Each single spectrum is taken in a 5 min. interval.**
- **http://xdb.lbl.gov/Section1/Periodic_Table/X-ray_Elements.html**

X ray gun voltage scan at 5 μA

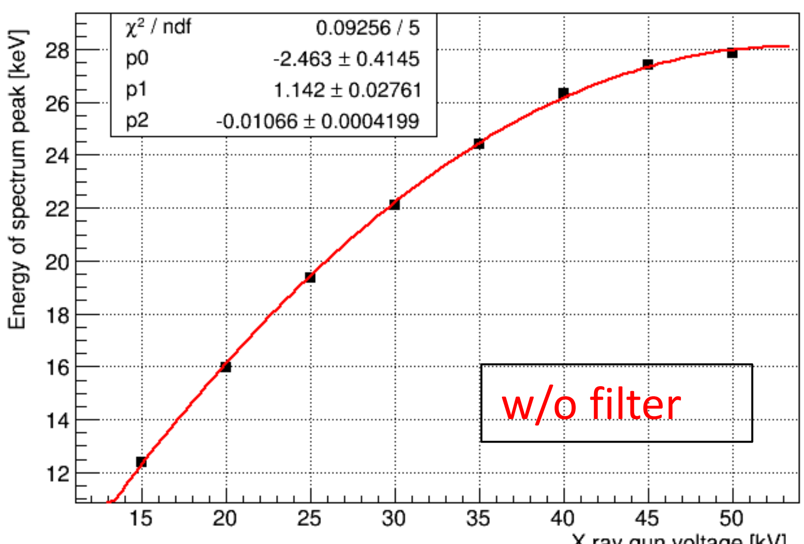
1 mm collimator

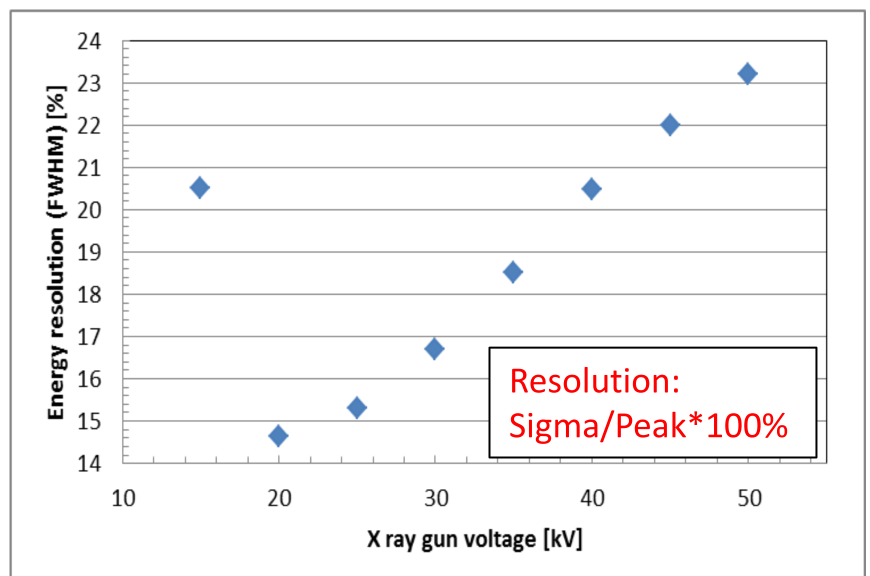


1 mm collimator



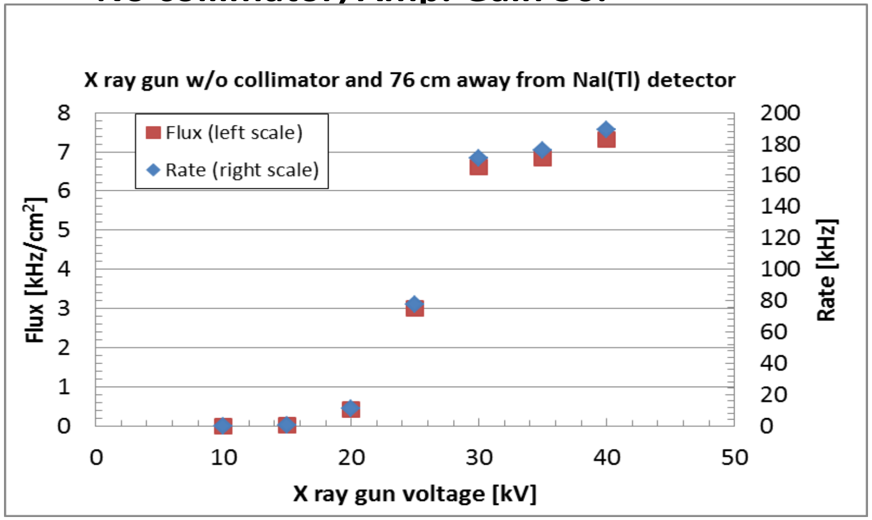
2 mm collimator; 76cm distance



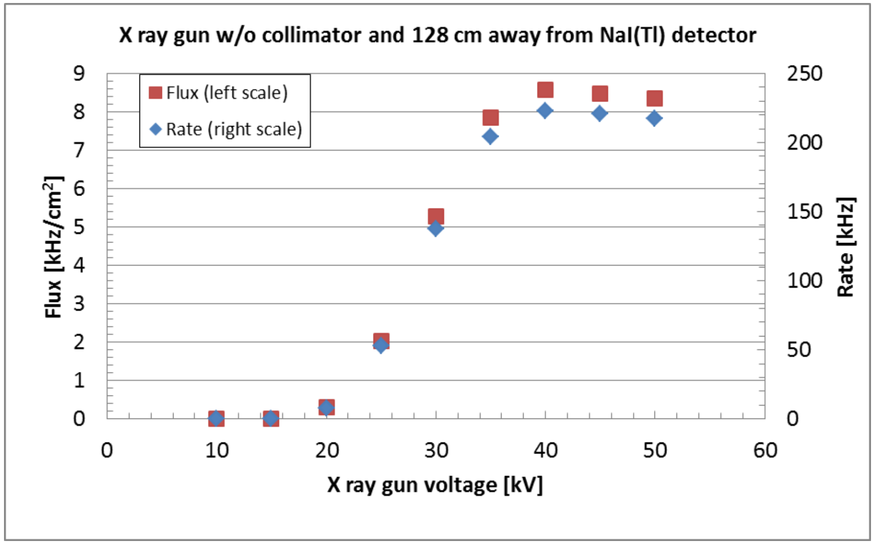


Rate and flux curves

X-ray gun 76 cm away from NaI;
No collimator; Amp. Gain 50.

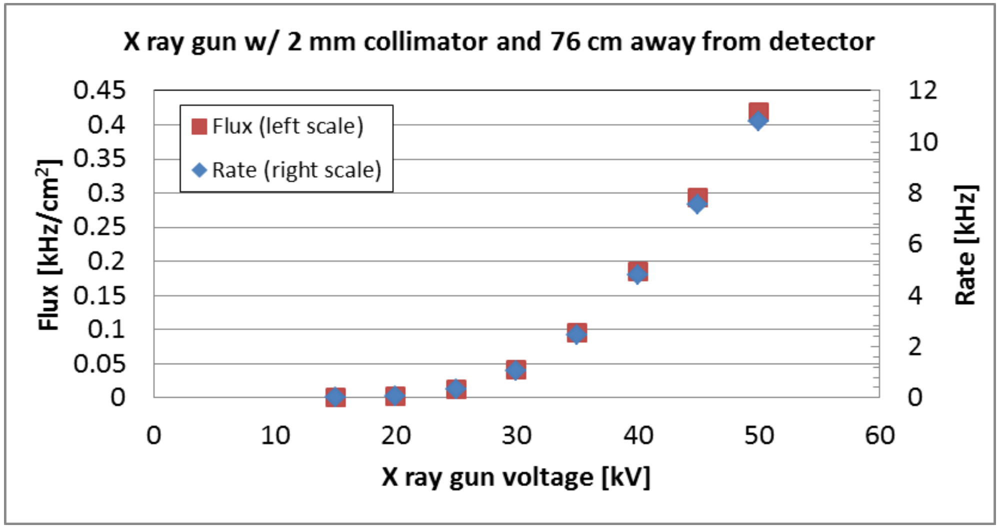


X-ray gun 128 cm away from NaI;
No collimator; Amp. Gain 500.



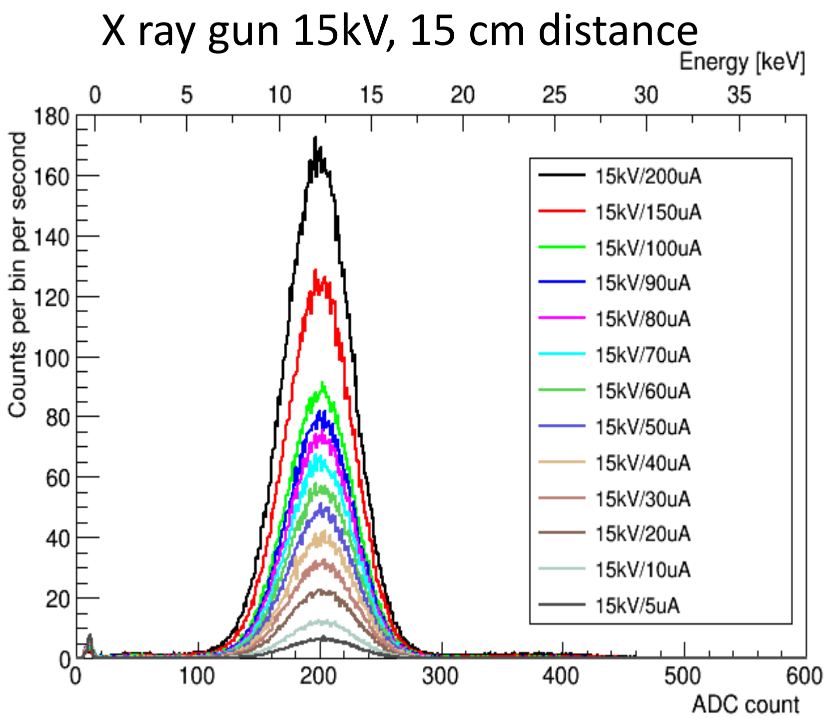
X-ray gun 76 cm away from NaI;
With 2mm collimator; Amp. Gain 500.

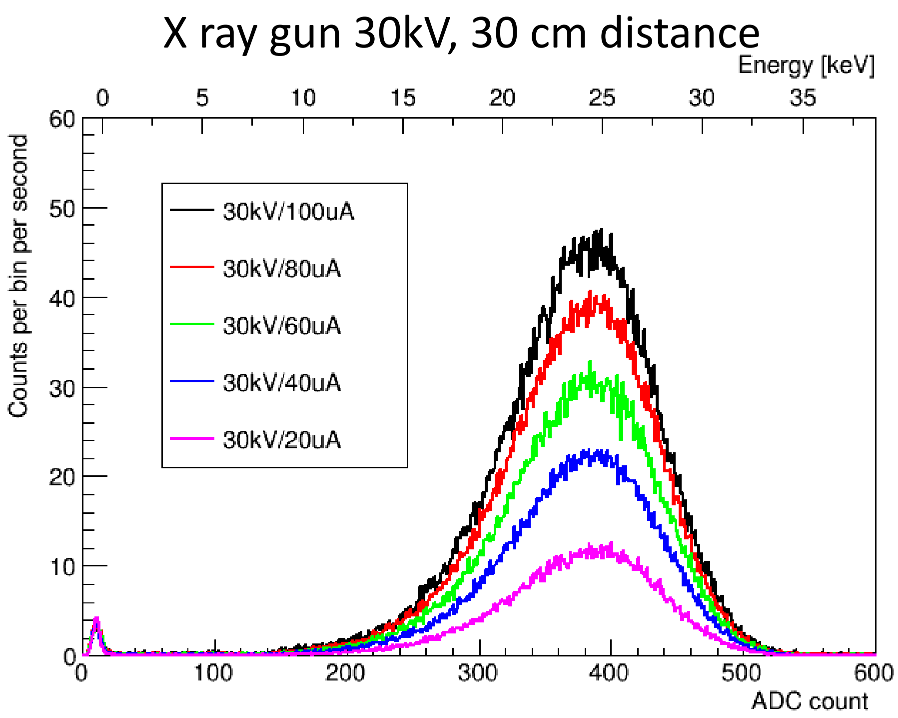
(when calculating the flux, I assume that the whole detector area is in the beam. Because the output X ray is in a 120° cone, and beam after collimator is not only perpendicular. See backup slide)



- For doing the measurements, threshold is 50 mV (the minimum of discriminator) for both amp gain 50 and 500 cases. This is fine because signals are well above 50 mV.
- Shaping time of amp. ~ 1 μs; width of signal from amp. is ~3 μs. So the max. rate that it can handle is ~0.3 MHz. Due to pileup events, the rate we can measure should be much less than 0.3 MHz.
- We are seeing plateau at rate around 0.2 MHz, where we already have a lot of pileup issue.

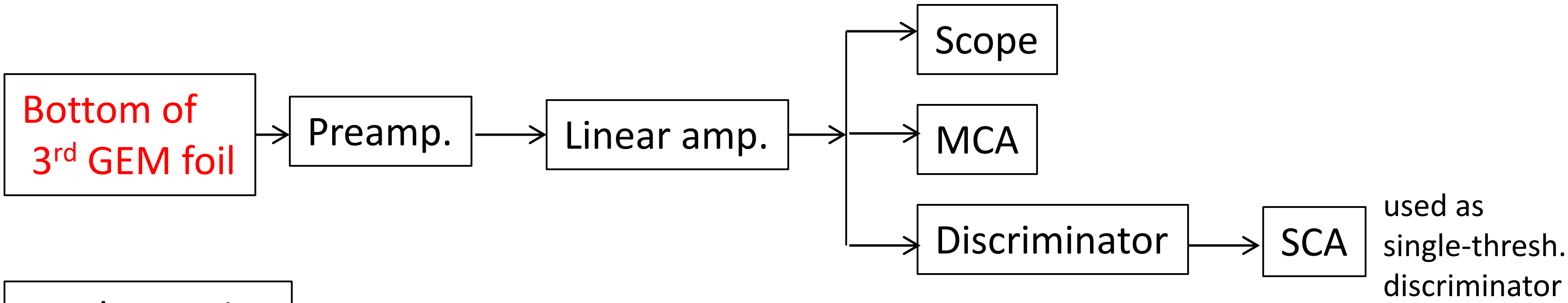
X-ray gun current scan, 1 mm collimator is used, No filter

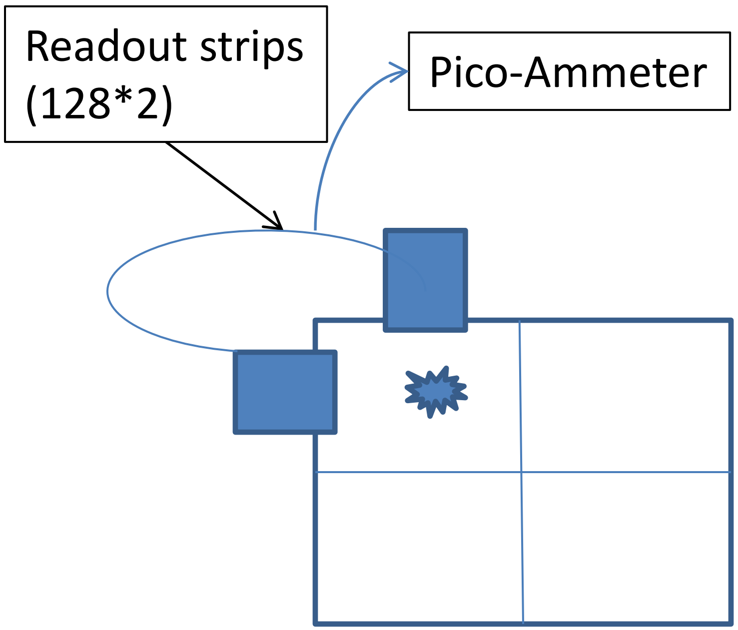




- Current of X ray gun controls the intensity, it has no influence on the X ray energy.

Results with std. Triple-GEM detector (10 cm × 10 cm)



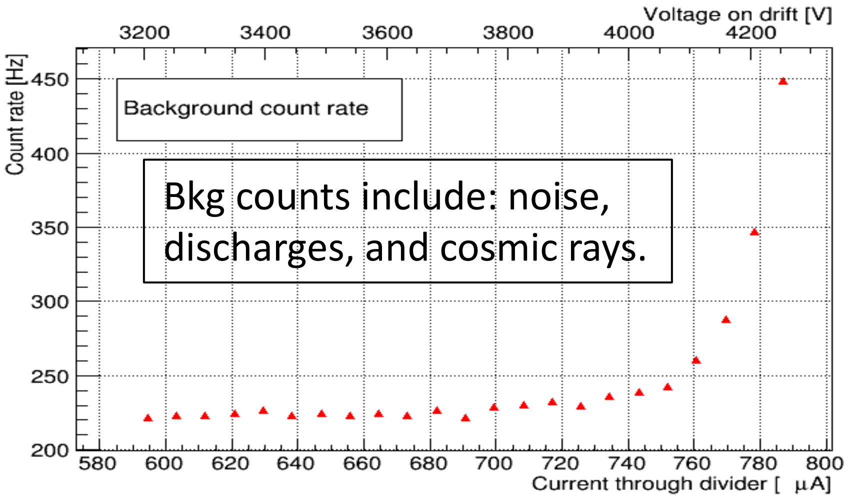


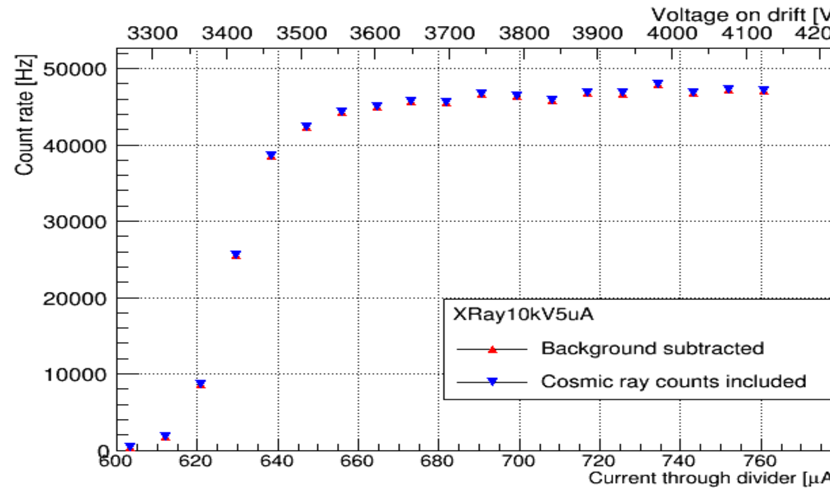
- The GEM gaps are 3/2/2/2 mm
- Gas used is Ar/CO_2 (70:30)
- Ceramic HV divider is used.
- An HV filter is used: 2 100 kOhm resistors and 1 2.2 nF capacitor. This reduces noise a lot!
- A standard 2D readout board is used.
- In order to record good current, X ray gun is put over one quadrant of the chamber and two Panasonic connectors are combined to output the current to pico-ammeter.
- Noise level from linear amp is <20mV when HV is off. It increases (to a 100mV level) when HV is on. Threshold is set to 50 mV. Background counts are subtracted (though they are small as compare to X ray counts from the X ray gun) when measuring rate.

All data presented below are based on pulses picked up from the bottom of the 3rd GEM that faces the readout

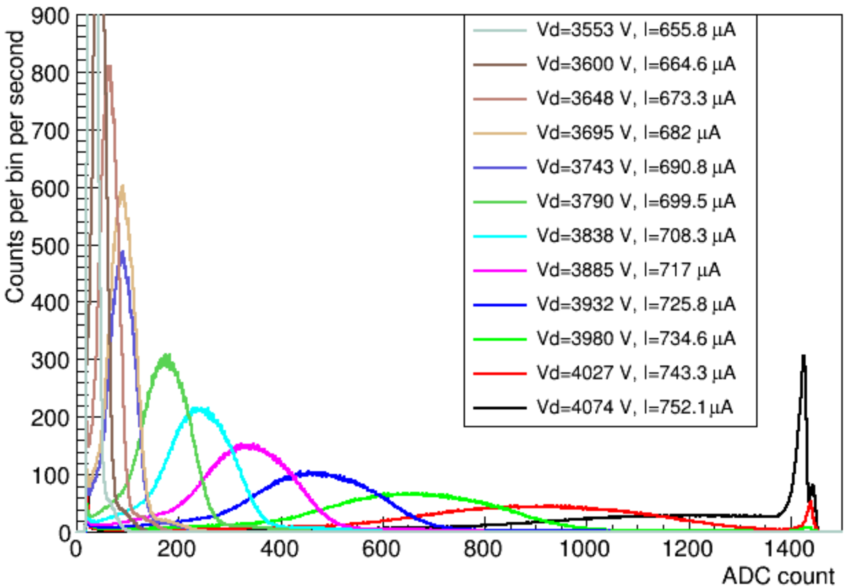
Rate curve and spectrum of X rays

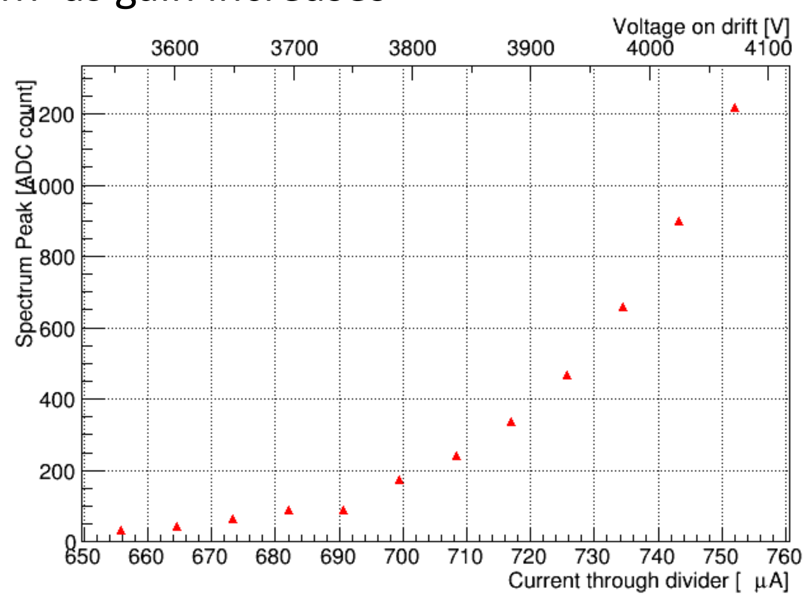
- X-ray at 10kV/5µA w/ 2 mm collimator, ~15 cm above the GEM.





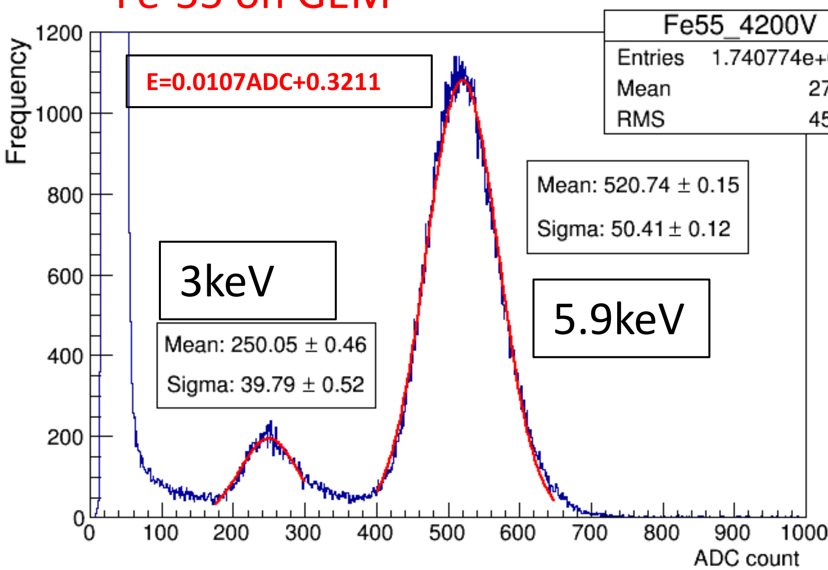
- Peak shifts to right when increasing HV on GEM as gain increases



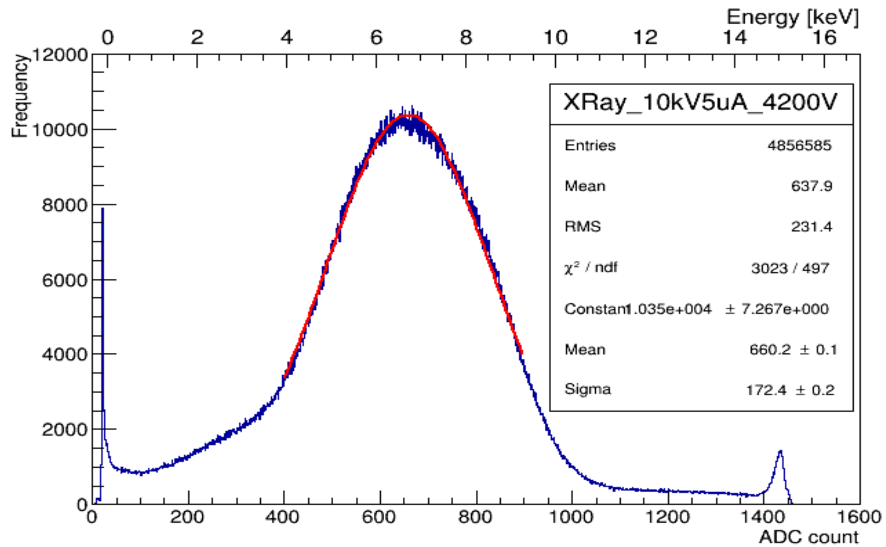


Calibration of X ray with Fe-55 source

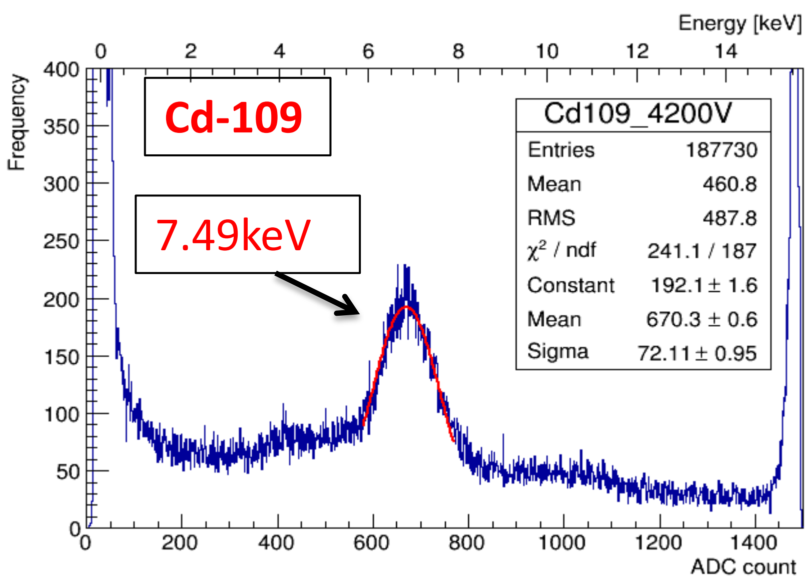
Fe-55 on GEM



X-ray gun on GEM (2 mm collimator, w/o filter)



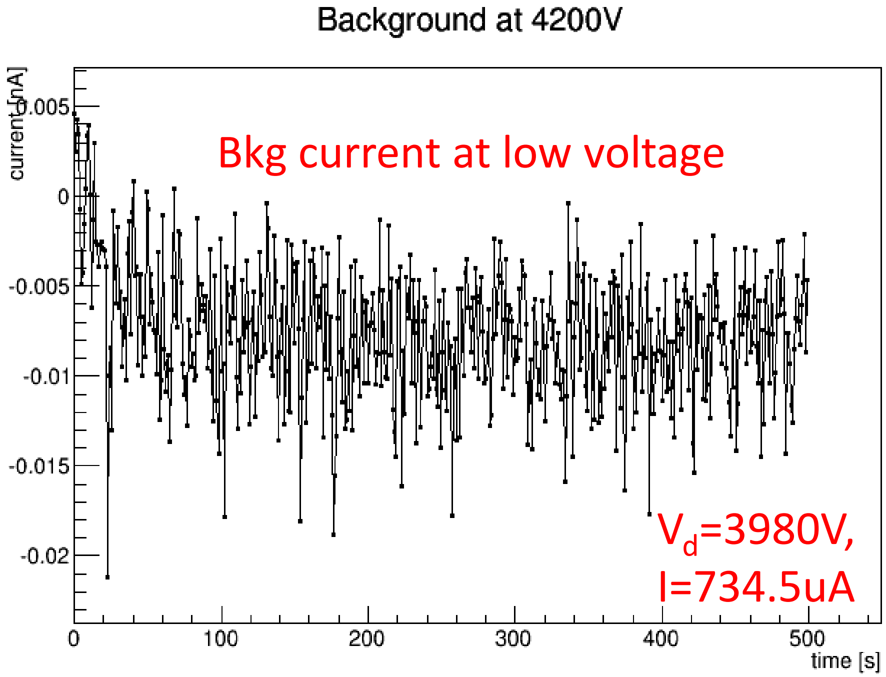
- Calibrated with Fe-55, X ray energy is <u>**7.39 keV**</u> @ 10kV/5uA settings.

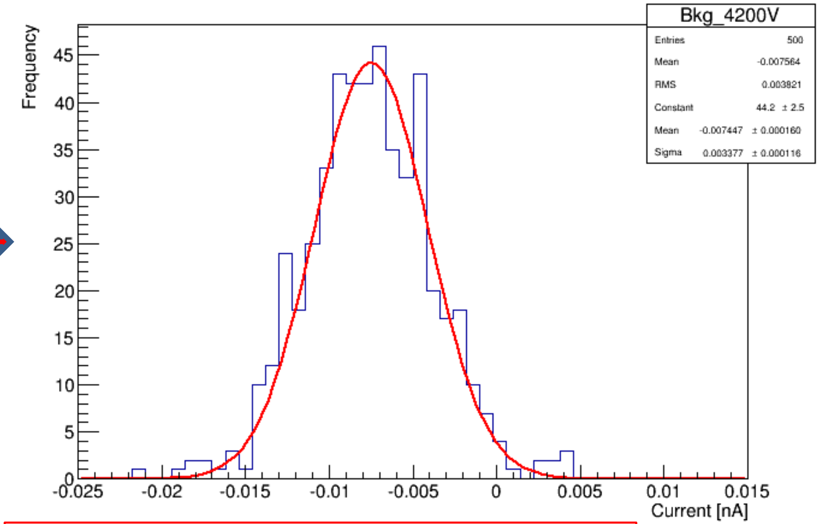


- Cadmium spectrum also indicates <u>**7.49 keV**</u> (peak).

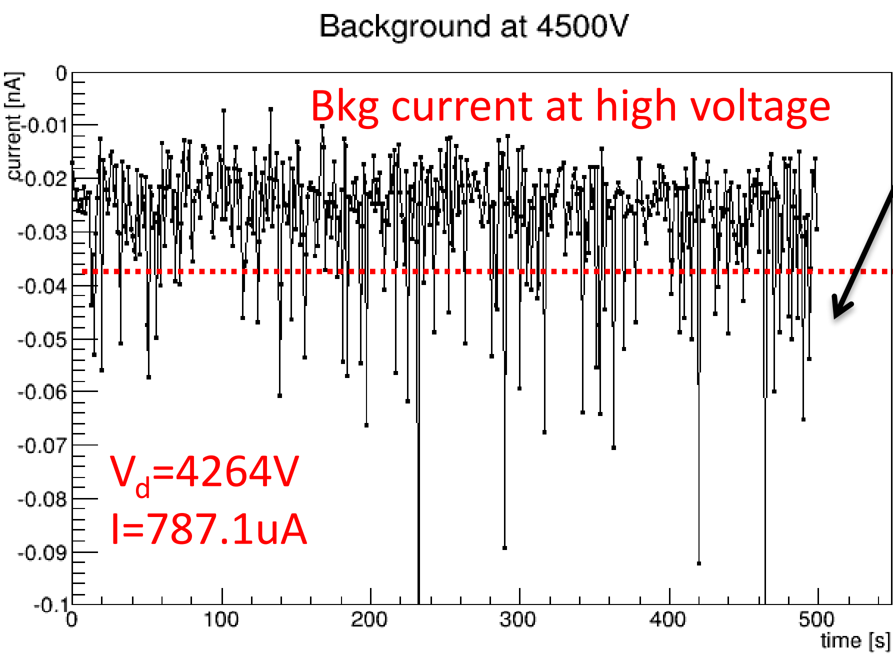
- One conclusion: This confirms that signals that are seen in GEM with the X-ray gun are from K lines (~8 keV) of copper due to x-ray fluorescence.

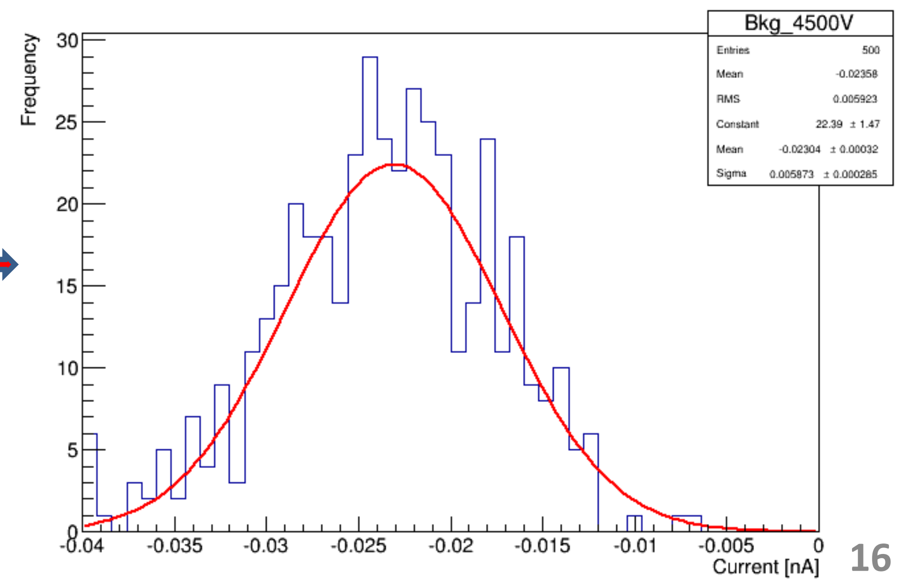
Current measured from readout strips (Bkg.)



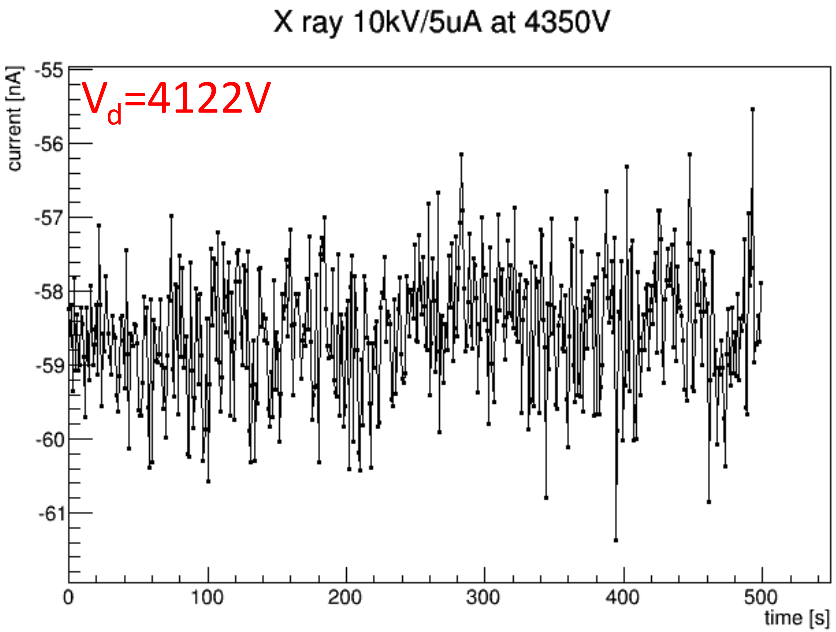


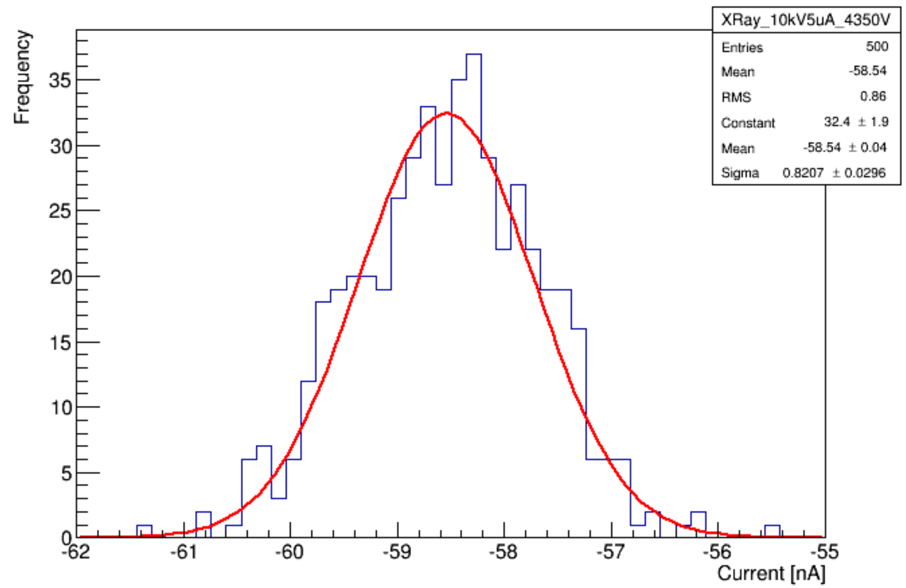
Cosmic signals show currents of > 0.04 nA





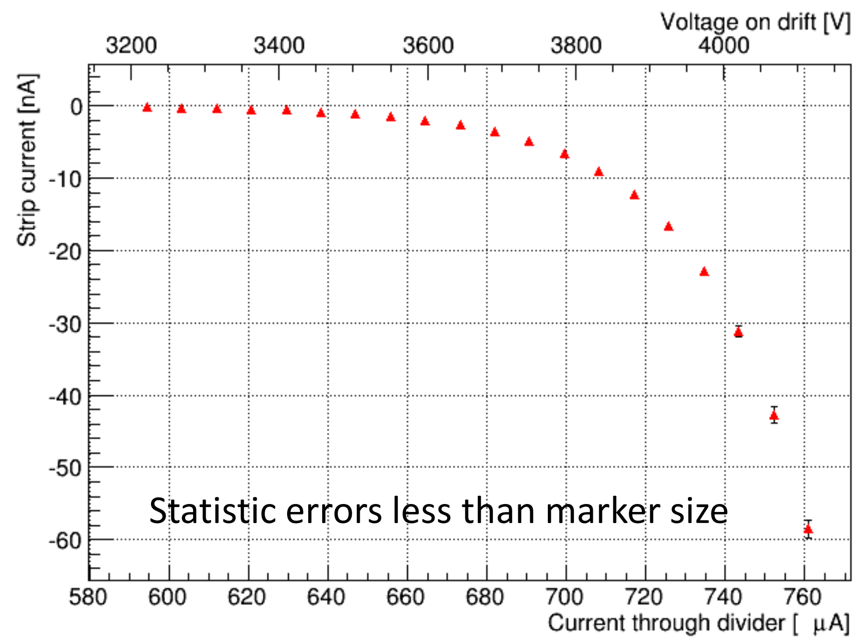
Current measured from readout strips (X-ray at 10kV/5μA)



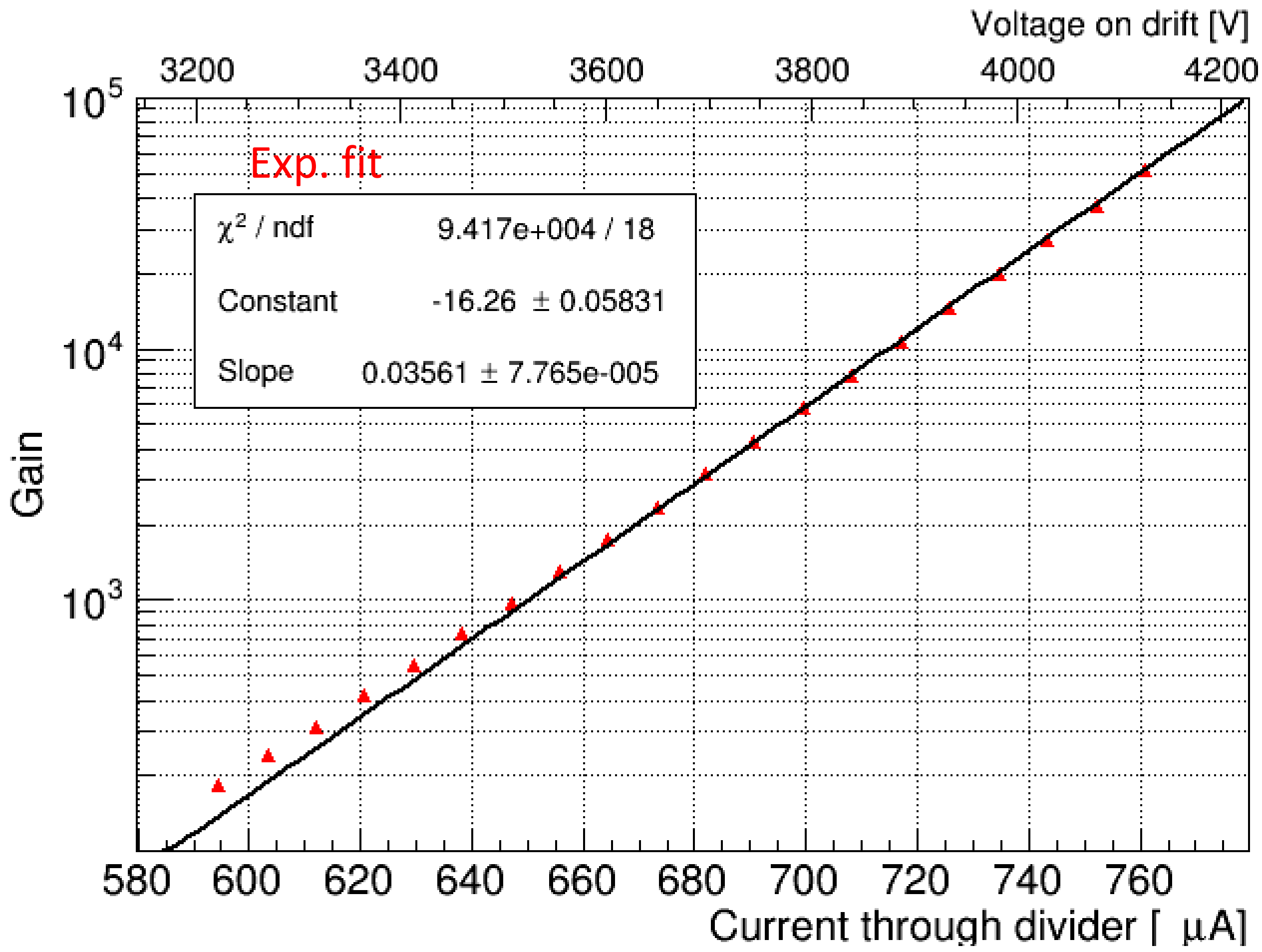


- At each tested voltage point, current is stable! The above two plots are for the highest tested point (V_d=4122V).

- Current on strip vs. current in divider is shown on the right.



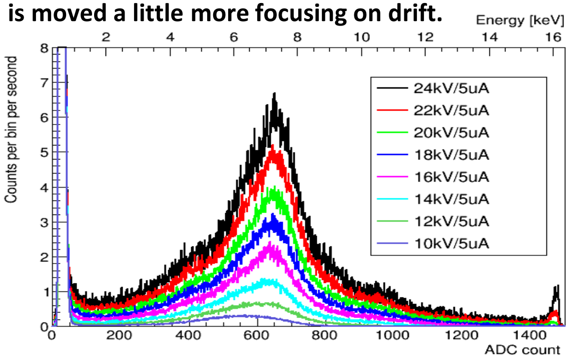
Gain curve


Voltage on drift [V]
3200
3400
3600
3800
4000
4200
Exp. fit
χ^2 / ndf 9.417e+004 / 18
Constant -16.26 ± 0.05831
Slope 0.03561 ± 7.765e-005
Gain
10^5
10^4
10^3
580
600
620
640
660
680
700
720
740
760
Current through divider [μA]

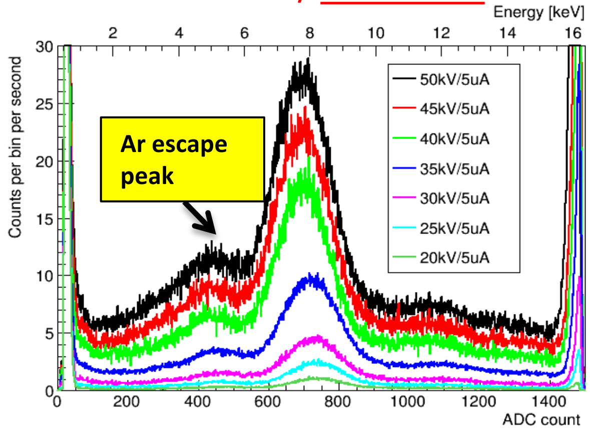
X ray spectrum at 5 µA, distance 45 cm, V_{drift} = 3980 V, I=734.5 uA, gain 2× 10^4

1 mm collimator / **No filter**

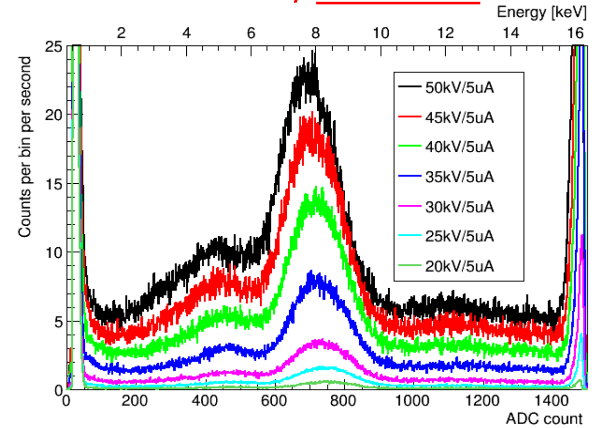
Rate is lower than others. Reason is the X ray hits mainly the honey-comb frame. For others the position is moved a little more focusing on drift.



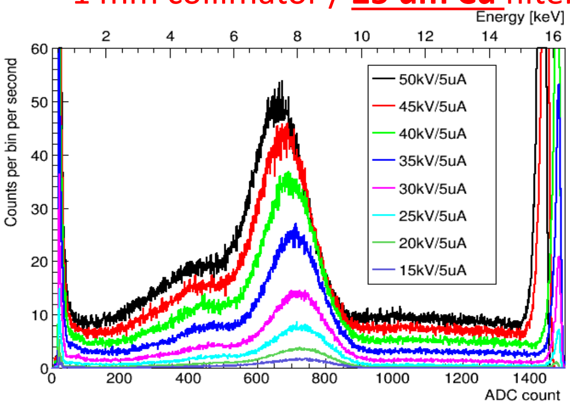
1 mm collimator / **250 um Al** filter



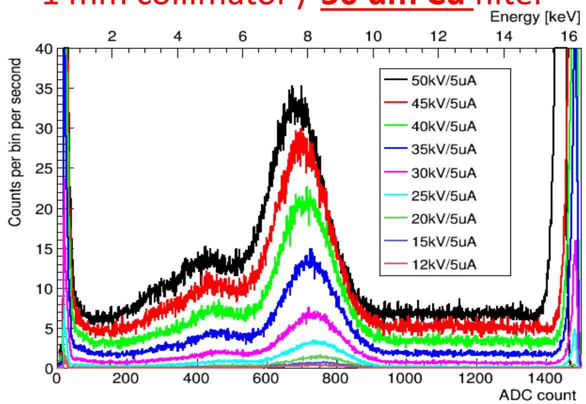
1 mm collimator / **500 um Al** filter



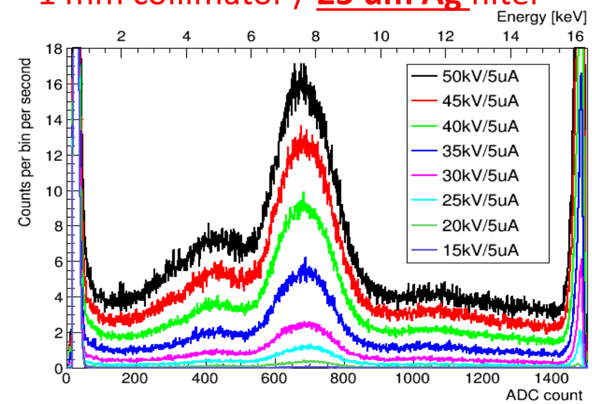
1 mm collimator / **25 um Cu** filter



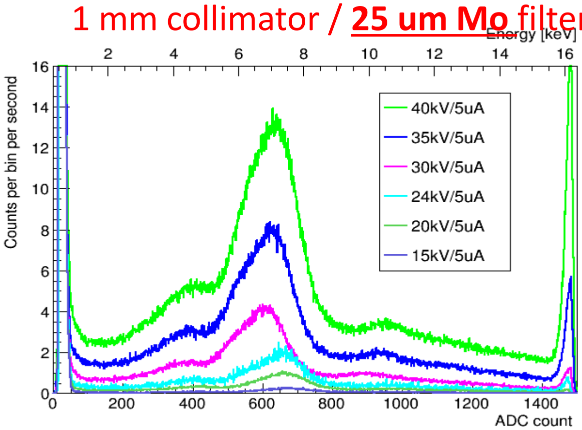
1 mm collimator / **50 um Cu** filter



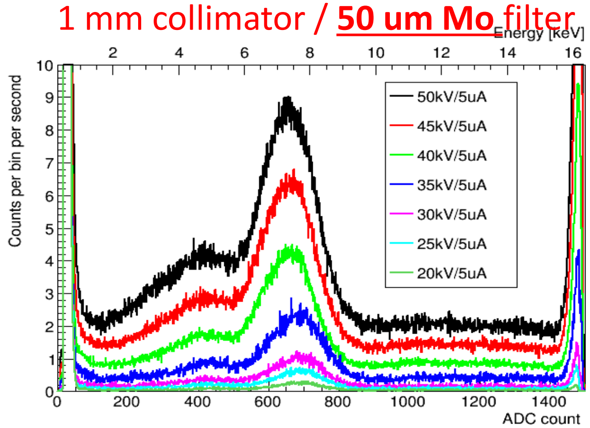
1 mm collimator / **25 um Ag** filter



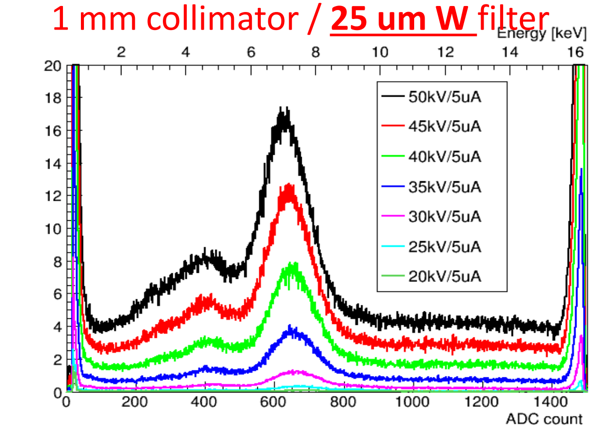
1 mm collimator / **25 um Mo** filter



1 mm collimator / **50 um Mo** filter

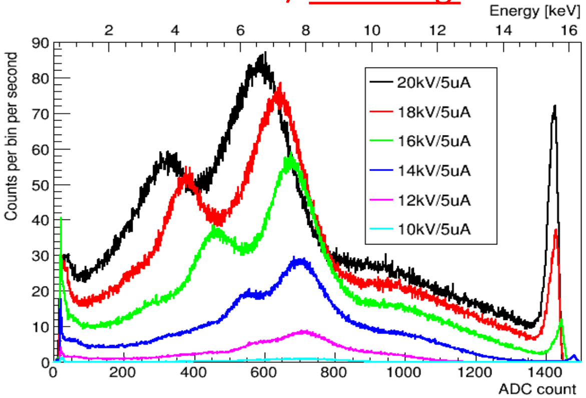


1 mm collimator / **25 um W** filter

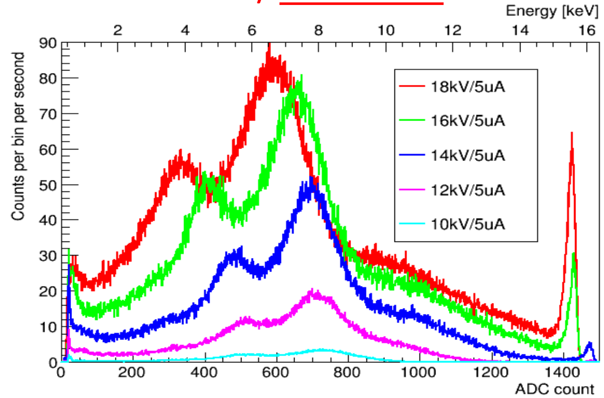


X ray spectrum at 5 uA, distance 45 cm, V_{drift} = 3980 V, I=734.5 uA, 2× 10^4

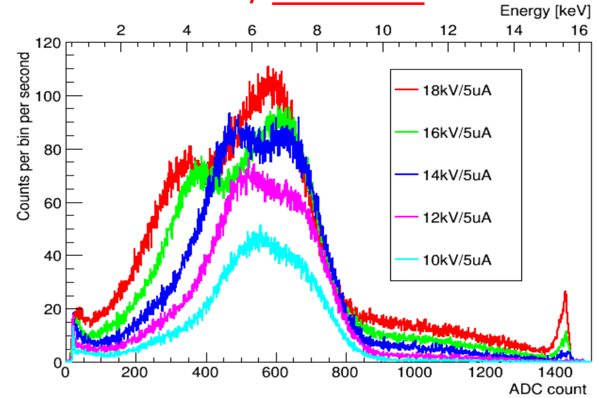
No collimator / 25 um Ag filter



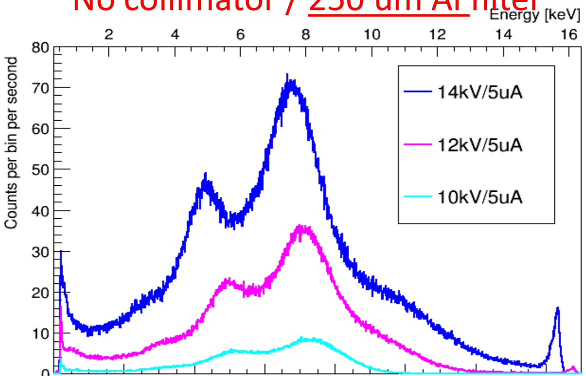
No collimator / 25 um Mo filter



No collimator / 25 um Cu filter

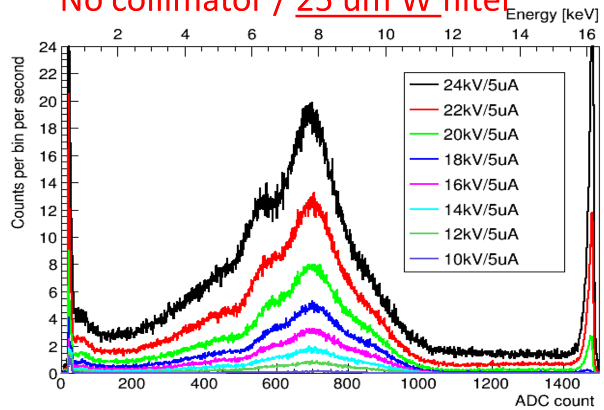


No collimator / 250 um Al filter



This looks like a useful filter!

No collimator / 25 um W filter



- Without collimator, there are many pile-up events at higher X ray voltage (high rate). So these data are taken at X-ray gun voltage not more than 24 kV.
- Pile-up pushes the peak on a spectrum to the left, i.e. to lower energy.

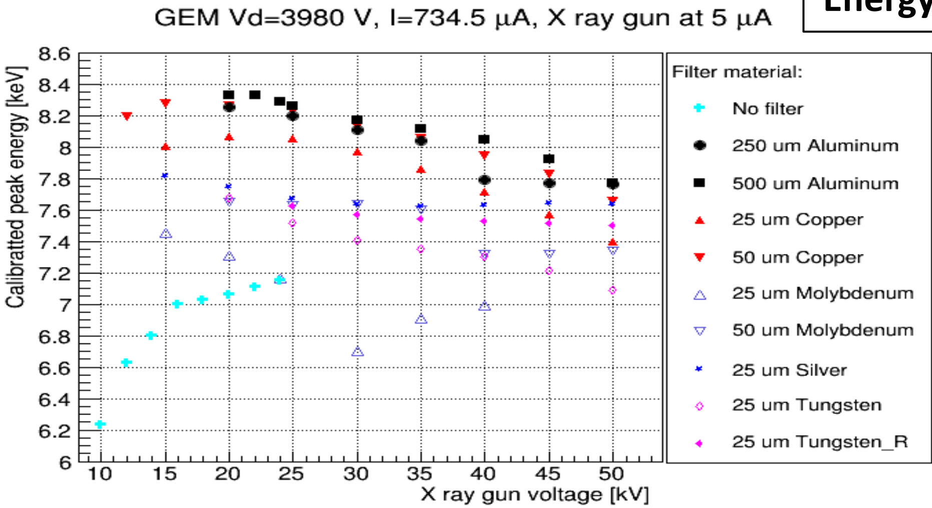
X-ray spectrum at 5 μA, distance 45 cm, V_{drift} = 3980 V, I=734.5 uA

- Calibrated peak energy vs. X ray gun voltage.

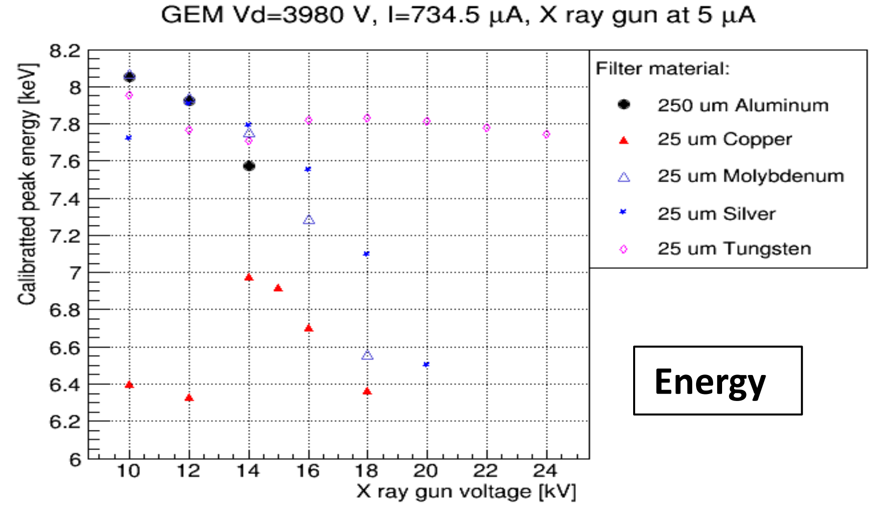
Table of fluorescence X ray energies of material

Material	K alpha [keV]
Cu	8
Al	1.5
Mo	17
Ag	22
W	58

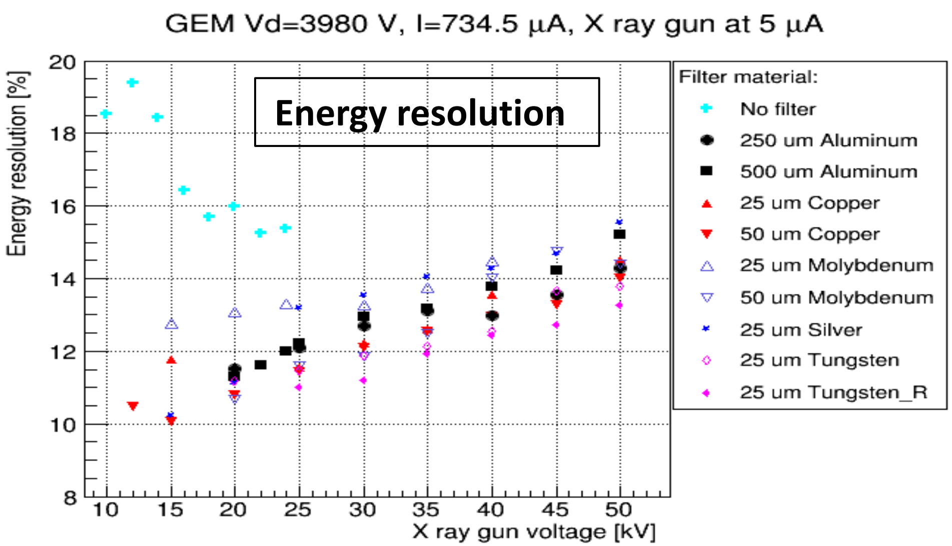
X ray on GEM, with 1 mm collimator

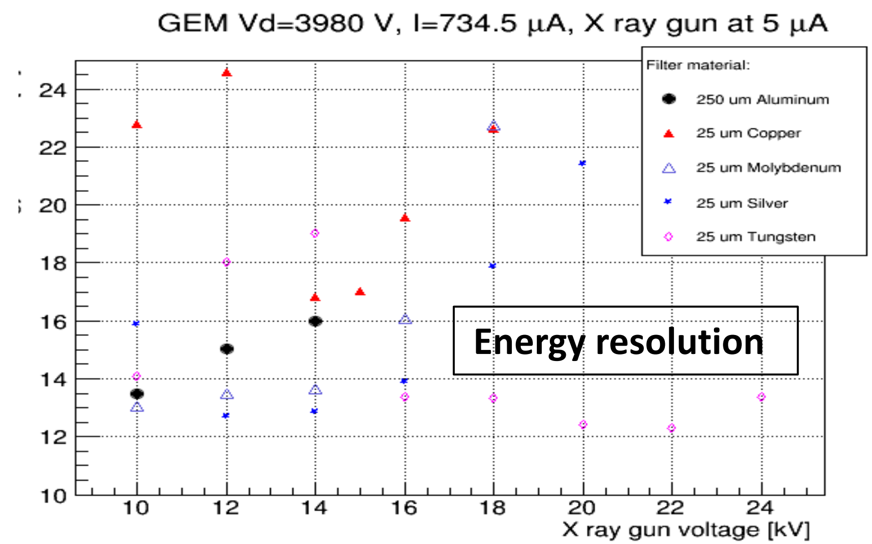


X ray on GEM, **NO** collimator



- **At lower X ray voltage, Al/Ag gives better energy resolution; at higher x-ray voltage, W filter gives better resolution.**





Summary

Tested the X-ray gun (Au target) with a commercial NaI(Tl) detector:

- Find out that the Cd-109 source in our lab is actually not pure, very likely it contains Ba-133 contamination.
- Scanned X ray voltage (energy) at fixed current (5 μA) and find that the measured X-ray peak energy is a quadratic function of the applied X-ray voltage.
- Also scanned X ray current at fixed voltage (15kV,30kV) , the energy peaks don't change at all; only rate changes. This confirms that the current does not change X ray energy.
- Some fluorescence X rays are recognized in the X ray gun voltage scan, such as: possibly K lines of Iodine (28-32keV), K lines of Ag (22keV), K lines of Mo (17keV).
- K lines of Cu (8 keV) are NOT measured (even with a Cu filter) due to a 0.5 mm Al window.
- The measurable flux of X ray from the gun reaches up to 8 kHz/cm^2 (rate ~200 kHz). This is limited by our slow electronics (~1 us shaping time, 3 us signal width, max. 0.33MHz w/o pileup).

Tested the X-ray gun (Au target) with a std. 10cm × 10cm Triple-GEM detector:

- Get good rate curve (plateau rate 44kHz) and gain measurement (5*10^4) with X ray gun.
- Confirmed that peaks in spectrum measured with the GEM are fluorescence X rays of copper.
- Tested different filter materials and scanned different X ray gun voltages. For future tests with large GEM detector, we expect to run the X ray gun at lower voltage. In that case, Al or Ag filter can be used to get better energy resolution, i.e. sharper peaks (photopeak and Ar escape peak).

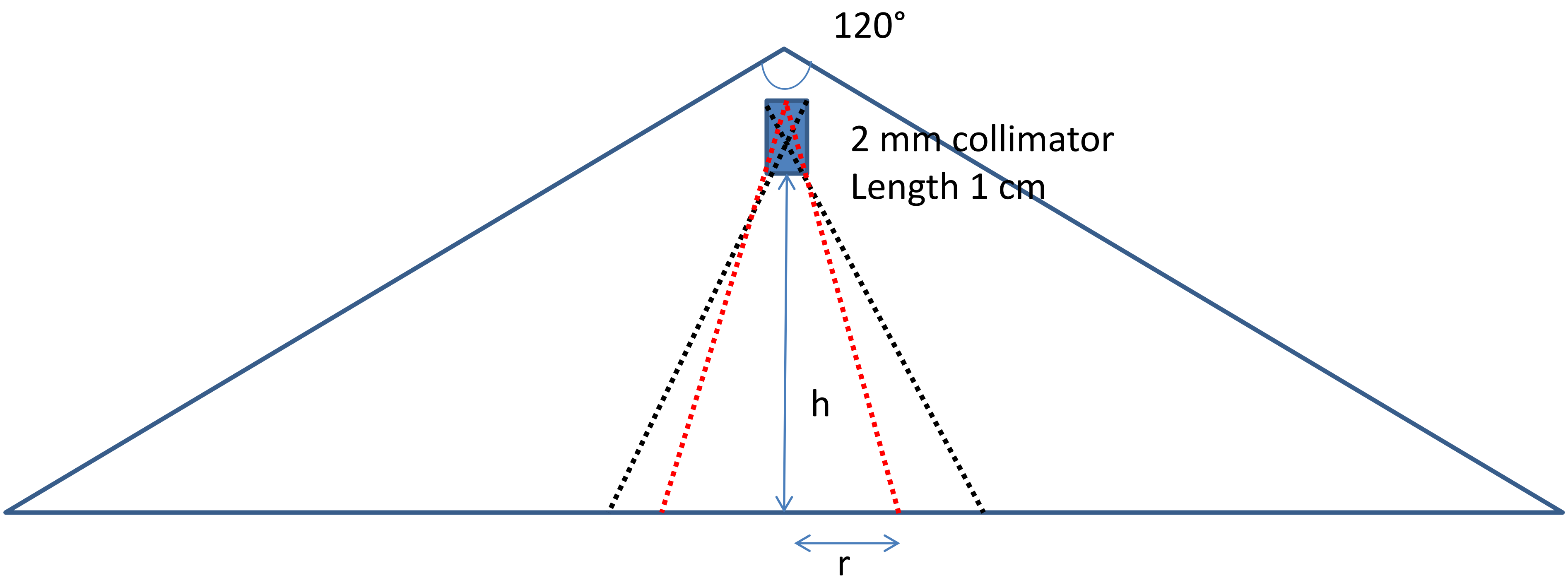
Next plan

- Fighting with noise on the large GEM detector and repeat these measurement, in addition, we will do uniformity scan on the detector.

-> X ray properties of element:

http://xdb.lbl.gov/Section1/Periodic_Table/X-ray_Elements.html

Backup – explanation of flux calculation on page 11



$$r = (h+1) * \frac{0.1}{1}\ (cm)$$

In case of h = 30 inch = 76.2 cm, r = 7.72 cm, larger than the NaI(Tl) size

Backup – energies of fluorescent X rays of elements in keV

Element	Atom number	K_α	L lines	M lines
Na	11	~1		
Al	13	1.486		
Fe	26	6.4		
Cu	29	~8		
Zn	30	8.6		
Mo	42	17.4		
Ag	47	~22		
Sn	50	~25		
I	53	28		
W	74	58~59		
Au	79	67~69	9~14	~3
Tl	81	70~73		

Backup material